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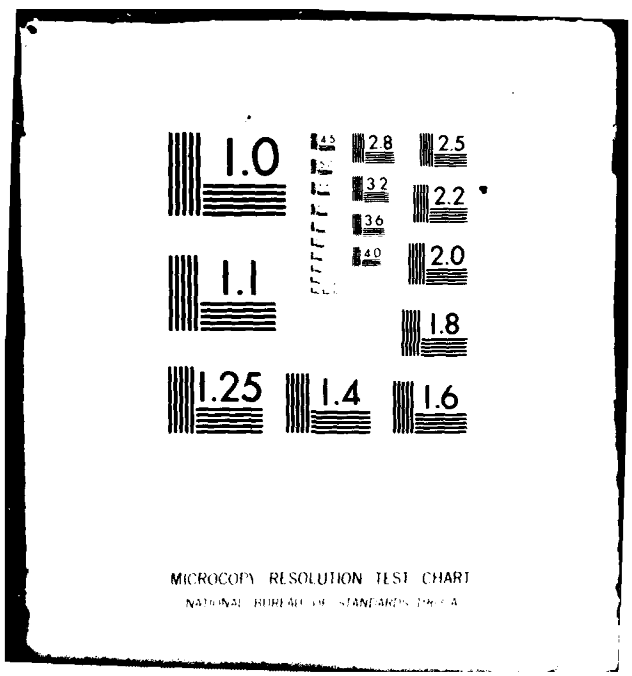
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TECHNION — ISRAEL INSTITUTE OF TECHNOLOGY
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DIFFERENT DIFFICULTY MANIPULATIONS INTERACT DIFFERENTLY WITH TASK EMPHASIS: EVIDENCE FOR MULTIPLE RESOURCES

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ABSTRACT

A two-dimensional pursuit tracking task was paired with three variants of a letter typing task to test predictions about the effects of task difficulty and task emphasis derived from a model of multiple resources, which states that tasks can overlap to various degrees in their demand for resources. Under dual-task conditions, when difficulty and priorities of tasks are jointly manipulated, difficulty parameters that tap processing resources shared by both tasks interact with priorities, while parameters that are relevant to one task only have additive effects on performance. In the present experiment a fixed difficulty tracking task was paired with a letter typing task on which difficulty was manipulated by varying cognitive or motor factors. In addition, task priorities were manipulated and the instantaneous difference between actual and desired performance was continuously displayed to the subjects. Task priority in dual-task conditions had large effect on the performance of the two tasks suggesting the existence of competition for resources. Both types of difficulty manipulations had large effects on performance. However, only motor difficulty interacted with priorities. The results are interpreted to indicate that joint performance of typing and tracking mainly compete for motor-related resources, while the size of the stimulus set tap a separate resource which is primarily relevant to the letter typing task.

DIFFERENT DIFFICULTY MANIPULATIONS INTERACT DIFFERENTLY WITH TASK EMPHASIS : EVIDENCE FOR MULTIPLE RESOURCES

In a recent article (Navon & Gopher, 1979) we discuss a multiple resource approach to the description of human performance limitations under time-sharing conditions. According to this approach the human processing system is regarded as possessing several mechanisms each having its own capacity. Concurrently performed tasks may overlap to various degrees in their demand for those capacities. Thus, while some components of each of concurrently performed tasks may compete for allocation of a common resource other components may tap resources that are relevant to one task only and hence be unaffected by the dual-task requirement.

Within such framework the main concern is the profile of demand compositons for each task, and the overlap of demands.

One possible strategy in attempting to validate the notion of multiple resources or to identify the various resources is to employ different manipulations of task difficulty that can be linked with different task elements, processing stages, or response mechanisms. Under single task conditions such manipulations may all lead to similar performance deficits that would teach us very little on the structure of the task involved in terms of demand compositions. However, in dual-task situations difficulty manipulations that call for drawing increased amounts of resources from a common pool to meet performance criteria on the manipulated task would cause respective impairments of performance on the other task. On the other hand those manipulations that impose demands primarily on independent resources would selectively affect performance only on the task the difficulty of which is varied.

The above prediction appears to be simple but its experimental testing can be obscured by considerations of subjects resource allocation policy. Increased difficulty on one task can either be met by recruiting more resources to the performance of this task in order to protect its performance, which requires a change in resource allocation policy. Alternatively, the portions of resources allotted to each task may remain unchanged, so that the increased difficulty of one task would result in larger performance decrements on that task reflecting the reduced efficiency of resources (see Navon & Gopher, 1979, Fig. 2). These two strategies are not mutually exclusive and some combination of both is very prevalent (see, e.g., reviews of dual task research, Ogden, Levine and Eisner 1979, Rolfe 1971, Williges and Wierwille 1979). If strategies are mixed or inconsistent the differential effects of different difficulty manipulations may be hard to reveal.

In previous papers (Gopher & Navon, in press, Navon & Gopher, 1979, Navon & Gopher, in press) we proposed that the nature of interaction between concurrently performed tasks and the degree to which it can be considered to be a capacity interference can best be studied when both task difficulty and task emphasis are systematically manipulated. When variables of difficulty and priorities are jointly manipulated their separate effects as well as their interaction can be studied. A detailed discussion of this proposition will not be repeated in this article. The most important prediction of this analysis is that sharing of a common resource by two concurrent tasks will be revealed as an interaction between difficulty and priorities of tasks. If joint performance is represented by POC curves (see Navon & Gopher, 1979, Norman & Bobrow, 1975) difficulty manipulations on one task that affect the efficiency of resources allotted from the common pool would affect the slope of these POC curves. In contrast, difficulty manipulations that do

not impose demand on a common resource would have additive effects to those of priorities. Similar predictions on the consequence of sharing versus independence of demands imposed on stages or processes were recently suggested by Logan (1979), although his argument was limited to decrements from single- to dual-task conditions; we already argued that such decrements are not necessarily indications for resource interference (Navon & Gopher, 1979).

With regard to the multiple resource approach it is important to show that within a single pair of tasks both additive and interactive relationships can coexist and depend on the kind of difficulty manipulation. Such an outcome is natural within a multiple resource framework but can hardly be accounted for by single capacity models (e.g. Kahneman 1973).

As we suggested already in previous papers, findings of this sort are useful when attempting to map demand compositions of various tasks. We set out to show that this is a feasible way.

A multiple resource interpretation of differential effects of difficulty parameters on performance under time-sharing conditions was suggested as a post-hoc account for the results obtained in an earlier study of tracking behavior (Gopher & Navon, in press). In that study, each of the axes (horizontal and vertical) of a two-dimensional pursuit task was treated as a separate task on which difficulty and relative emphasis were jointly varied. Experimental results were interpreted to indicate that tracking tasks can be conceived to demand at least two kinds of resources: one is a "computationsl" or "perceptual" resource; the other is a "motor" related resource. It was further suggested that it is for the use of the latter resource that tracking tasks mainly compete in dual axis tracking.

To verify these suggestions on the demand composition of tracking tasks and provide additional experimental tests of the multiple resource notion, the tracking task employed in the previous study was paired with a code typing task. Tracking difficulty remained constant throughout the experiment, while cognitive load and response difficulty were varied on the typing task. In addition, allocation policy was manipulated by employing three levels of intertask priorities in dual-task conditions.

METHOD

Experimental Tasks

Tracking: A dual axis pursuit tracking task served as one experimental task. Subjects were seated at a distance of approximately 70 cm from a CRT screen (22 x 22 cm about 18 degrees visual angle) on which a square and an X figures (1.5 x 1.5 cm) were displayed (Figure 1). The square served as a target symbol and moved continuously along the two dimensions of the screen, driven by a band limited, random, forcing function with a cutoff frequency of .7Hz, controlled by a second order digital filter. The X symbol was controlled through a single, two-dimensional spring loaded, hand controller. Right and left deflections of the hand controller moved the X on the screen in the horizontal axis, while fore and aft delfections were translated into up and down movement on the screen respectively. Hand controller deflections did not affect the position of the X on the screen directly but rather changed the acceleration component of its movement. Control dynamics generally followed the equation

(1) $\theta = (1 - \alpha)\ 0.75\ (\text{velocity}) + (\alpha)\ 0.3\ (\text{acceleration})$

Theta represents control system output. Alpha values in equation (1) were manipulated to vary the relative contribution of velocity and accele-

ration components to system response.

The tracking system was installed on the right hand side of the subjects' chair and operated by the right hand.

Insert Figure 1 about here

Code typing task: The code typing task was based on a 3 key typewriter for the Hebrew language, developed by Gopher & Eilam (1979). In the Letter-Shape keyboard every letter of the Hebrew Alphabet is entered by two successive chords, each comprised of some combination of the three keys.

Letter codes can be best envisioned within a six cell imaginary matrix in which three columns represent the three keys and two rows represent the two successive chords (Appendix A). The codes were designed to resemble as much as possible the graphic form of the letters in printed Hebrew. For this purpose each of the cells in the imaginary matrix was treated as a graphic element. Letter forms were created similar to the way that symbols in graphic displays are constructed from dots and strokes. Some examples of different letter codes are presented in Appendix A.

The code typing task was a self-paced reaction time task. Single letters were displayed inside the square target of the tracking task (see Figure 1). This was done in order to avoid as much as possible interference due to peripheral vision. Subjects had to cancel them by typing the code of the displayed letter. If the correct code was typed, the letter disappeared and after an interval of 100 msec another, randomly selected letter was displayed. If incorrect codes were repeatedly entered or subjects failed to respond within a time interval of 3 seconds, the displayed letter was automatically changed by the computer.

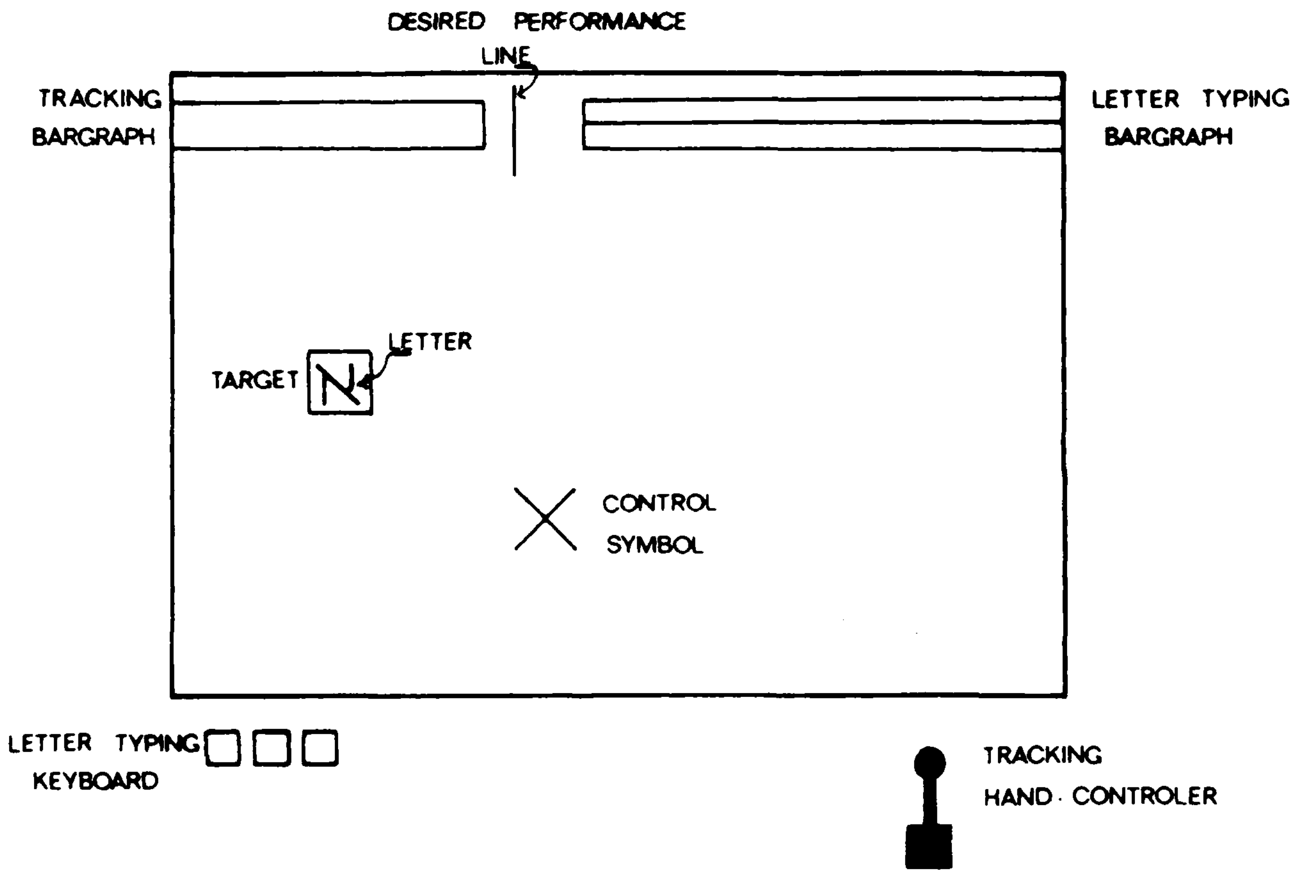

Fig. 1: Subject's display in the concurrent performance of tracking and letter typing.

In a different version of the code typing task, the subject could write each letter on the screen by typing the proper code. This version was used for initial training on the task.

Procedure

Experimental sessions: All subjects participated in four experimental sessions of 2.5 hours each.

The first session was devoted to initial familiarization and training on the experimental tasks. Subjects were presented with the Letter-Typing task and practiced it until they were able to type all letters twice without error. Training was preceded by 20 two minute trials on the code typing task, using the set of all 22 Hebrew letters, followed by 6 trials in which only the three subsets of letters to be used in the experiment were presented. In addition, 12 three-minute trials of adaptive tracking were interweaved in the letter typing trials. Adaptive techniques were employed to increment tracking difficulty by gradually increasing the proportion of acceleration determinants in the control functions of the hand controller, whenever tracking errors were lower than the specified criteria of performance. Performance criteria in the adaptive equation were 10 percent of scale root mean square errors (RMS) on each axis and adaptive steps were .0005 for every 60 msec computer decision cycle.

In the second session each subject performed nine three-minute dual-task trials, in addition to six trials of letter typing task alone and two trials of tracking alone. Single task trials were given in order to obtain the baseline performance levels for the manipulation of task priorities. In sessions 3 and 4, dual task manipulation of difficulty was conducted. In each of the two sessions, which were identical in structure, a total of 21, three-minute trials were performed. Difficulty

and priorities were manipulated in dual task conditions. Single task performance was also measured to contrast single and dual task levels.

Difficulty manipulation of the letter typing task: Three sets of letters were used to create different levels of difficulty:

a) A set of 4 easy letters: This set comprised 4 letters in which the two successive chords were identical (Appendix A).

b) A set of 4 difficult letters: Letters in which chords were different and asymmetrical (Appendix A).

c) A set of 16 letters: This set included the 8 letters of the two former sets and eight additional letters of medium difficulty (Appendix A).

The letters for all three sets were selected empirically by the results of an initial reaction time test. The set of 16 letters represented an increase of cognitive load compared to the set of 4 easy letters, while the 4 letters in set b) seem to primarily increase the difficulty of motor response. Tracking difficulty remained constant throughout the experiment at the level obtained by each subject at the end of adaptive training.

Priority manipulation by feedback indicators: Subjects were presented with an on-line continuous feedback on their performance. Feedback indicators comprised a short, static vertical line and two moving horizontal bar-graphs (see Figure 1). The static line represented the desired level of performance in terms of tracking error and correct response time to letters. Desired performance was determined in reference to a normalized baseline distribution of performance obtained for each subject at the end of the second training session. Subjects were generally required to perform the tasks in the dual task condition at their average level

in single task performance. The gap between the moving bar-graph on each task and the desired performance line reflected the momentary difference between actual and desired performance. This difference was computed continuously by subtracting the momentary error score (for tracking) and reaction time score (for letter typing) from the desired score and dividing the outcome by the standard deviation of the baseline distribution.

The right side bar-graph represented performance on the letter typing task and the left side bar-graph represented tracking performance.

Task priorities were manipulated by moving the desired performance line from the center (equal priorities) to the left side (high priority of letter typing and low priority of tracking) or to the right side (high priority of tracking and low priority of letter typing). A priority level of, say, .70 for tracking corresponded to a level of performance that assumed the 70th percentile in the baseline distribution of tracking performance for that subject. That is, an instruction to put priority of .70 was actually a requirement to perform at a level better than the lowest 70 percent of the baseline performance levels.

The use of a single vertical desired performance line with horizontal bar-graphs in this experiment is a change from the display used by Gopher & North (1977) and Gopher & Navon (in press). The present display has several advantages over the old procedure, since it reduces the use of peripheral vision and enhances the ability of subjects to compare directly the relative differences of the two bar-graphs from desired performance.

Verbal Feedback and Monetary Rewards

In order to motivate subjects and encourage them to maintain the required allocation of effort, verbal feedback and monetary reward systems were used during experimental sessions 3 and 4. In the beginning of each

trial subjects were instructed on the expected level of performance for that trial. At the end of the trial they were informed on their actual level of performance. In addition, they received monetary reward in each trial. At the end of each trial mean distance between actual and desired performance was computed for each task. The reward was inversely proportional to the longer distance between actual and desired performance on the two tasks. If the subject reached the demand levels on both tasks he received 10 Israeli pounds (about .3 U.S.$) for that trial. A distance of two standard deviations from desired performance on one task resulted in zero reward. The unique property of this reward procedure was that it discouraged subjects from allocating all their resources to one task and neglect performance on the other task.

Experimental Conditions

As indicated before sessions 3 and 4 were comprised of 21 trials each. Three levels of difficulty on the letter typing task (three sets of letters) were crossed with 3 levels of inter-task priorities (.7, .3; .5, .5; .3, .7) in a complete 3 x 3 factorial design of dual-task conditions. In addition, dual-task performance without bar-graphs was given as a control condition in all combinations of tracking with letter typing sets. Finally, each of the variants of the typing task as well as the tracking task were administered in a single task condition.

Order of conditions and sets of letters were counterbalanced across subjects.

Subjects

Six male, right-handed subjects (aged 19-25) participated in the experiment. Subjects were paid hourly rates during sessions 1 and 2 and earned monetary rewards on their performance during sessions 3 and 4.

RESULTS

Initial Training

Letter typing: At the end of twenty 2-minute trials in which the whole set of 22 Hebrew letters was practiced, subjects reached a mean reaction time of 1230 msec.per letter. The fastest subject reached an average level of 1065 msec.per letter and the slowest reached an average of 1448 msec. Performance on the last four trials showed considerable stability. The mean reaction time differences between trials 17-20 were smaller than 4 percent.

Average reaction times on the three sets of letters at the end of the first session were as follows:

4 easy letters	- mean RT 906 msec. range 760-1018 msec.
16 letters	- mean RT 1242 msec. range 1053-1370 msec.
4 difficult letters	- mean RT 1327 msec. range 1122-1634 msec.

Tracking: During the first experimental session, subjects performed 12 trials of adaptive tracking. The average final levels of acceleration (α levels in equation (1)) reached by the subjects were .735 (range .625-.830) on the horizontal dimension, and .480 (range .320-.655) on the vertical dimension.

The lower level of acceleration reached on the vertical axis reflects the larger difficulty of tracking on this dimension and is consistent with earlier experiments with this task (Gopher & Navon, in press). Nevertheless, on both axes the proportional contribution of the acceleration component was large enough to create a relatively difficulty control dynamics.

Acceleration levels on the last 3 adaptive trials generally reached asymptotic levels for all subjects.

In the second experimental meeting subjects were introduced to dual-task conditions. The objective of this meeting was to familiarize subjects with the experimental situation and detailed reports of these results are not presented. At the end of this meeting subjects were given two trials on each of the three letter sets and two trials of tracking with fixed levels of difficulty. Those were given to obtain the desired performance levels for the priority manipulation in session 3.

Average reaction times for the three letter sets were: a) Four easy letters .990 msec; b) Four difficult letters 1310 msec; c) Sixteen letters 1270 msec. Note that these are averages across subjects, but the demand levels for each subject were adjusted to fit his own achievement.

Tracking performance was measured in terms of root mean square (RMS) vector errors of vertical and horizontal differences between target (t) and control (c) screen positions ($\sqrt{(X_t-X_c)^2 + (Y_t-Y_c)^2}$). Tracking error scores were expressed in percent of scale units. The average tracking error score across subjects at the end of the second meeting was .267 RMS error.

<u>Joint Manipulation of Difficulty and Priorities</u>: Table 1 summarizes the main results obtained for the performance of letter typing. The table reveals clear effects of task priorities, difficulty type and practice (sessions III and IV).

A three way analysis of variance (Difficulty x priority x sessions) was conducted to test the statistical significance of those results. All main effects were highly significant, letter set difficulty ($F(2,10)$ = 62.3; $P < 0.001$), priority effects ($F(3,15) = 47.9$; $P < 0.001$) and

experimental session (practice) ($F(1,5) = 12.8$; $P < 0.025$).

The interaction between difficulty and priority also reached statistical reliability ($F(6.30) = 2.77$; $P < 0.05$) (see Figure 2). In order to determine the source of this interaction, separate analyses of variance were performed for each of the two types of difficulty manipulations. In each analysis performance on the 4 easy letter set was compared with one of the two difficulty manipulations.

The results of this analysis yielded a significant difficulty by priorities interaction for the 4-easy and 4-difficult letter sets ($F(3,15) = 5.46$; $P < .01$). No such interaction was found when performance on the 4-easy and 16 letter sets was analysed ($F(3,15) < 1$. The main differences between the two manipulations, the effects of priorities and the interaction between difficulty and priority on the 4-difficult letter sets are clearly revealed in Figure 2. The differences in performance

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Insert Figures 2 and 3 about here

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between the three sets of letters were already manifested in single task conditions and were statistically significant ($F(2,10) = 24.5$; $P < .001$). Note that average reaction time for the set of 4 difficult letters was lower than the average obtained for the 16 letters set ($P < .025$ in a Schaffe paired comparison) although the differences between the two were reversed in dual task conditions (Fig. 2), that is, larger decrements were observed in typing performance on the 4-difficult letter set.

Tracking Performance: Tracking errors were measured every 60 msec. and integrated over 15 second intervals. The 12 values obtained in this manner for each 3 minute trial were averaged to yield an overall performance score for that trial.

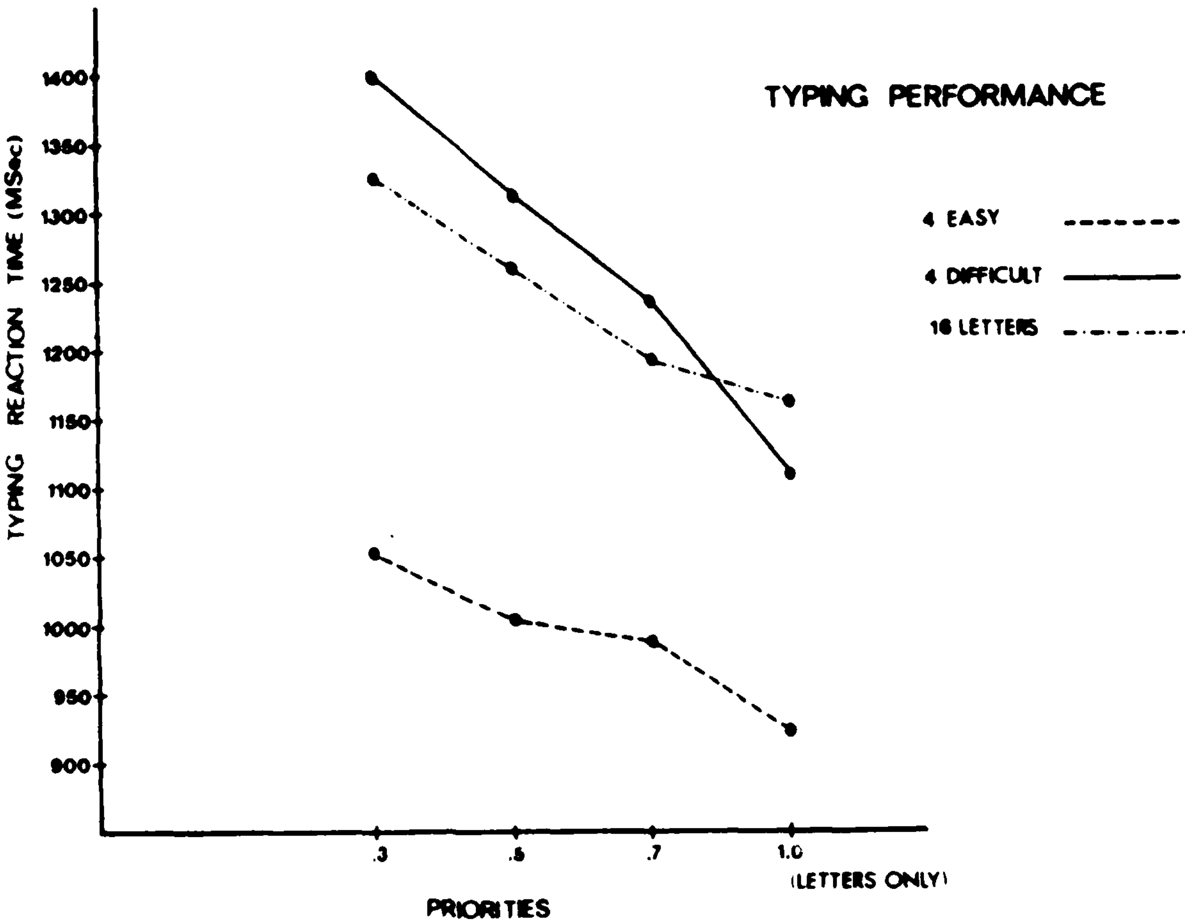

Fig. 2: Typing performance on the three sets of letters as a function of task emphasis under time-sharing conditions.

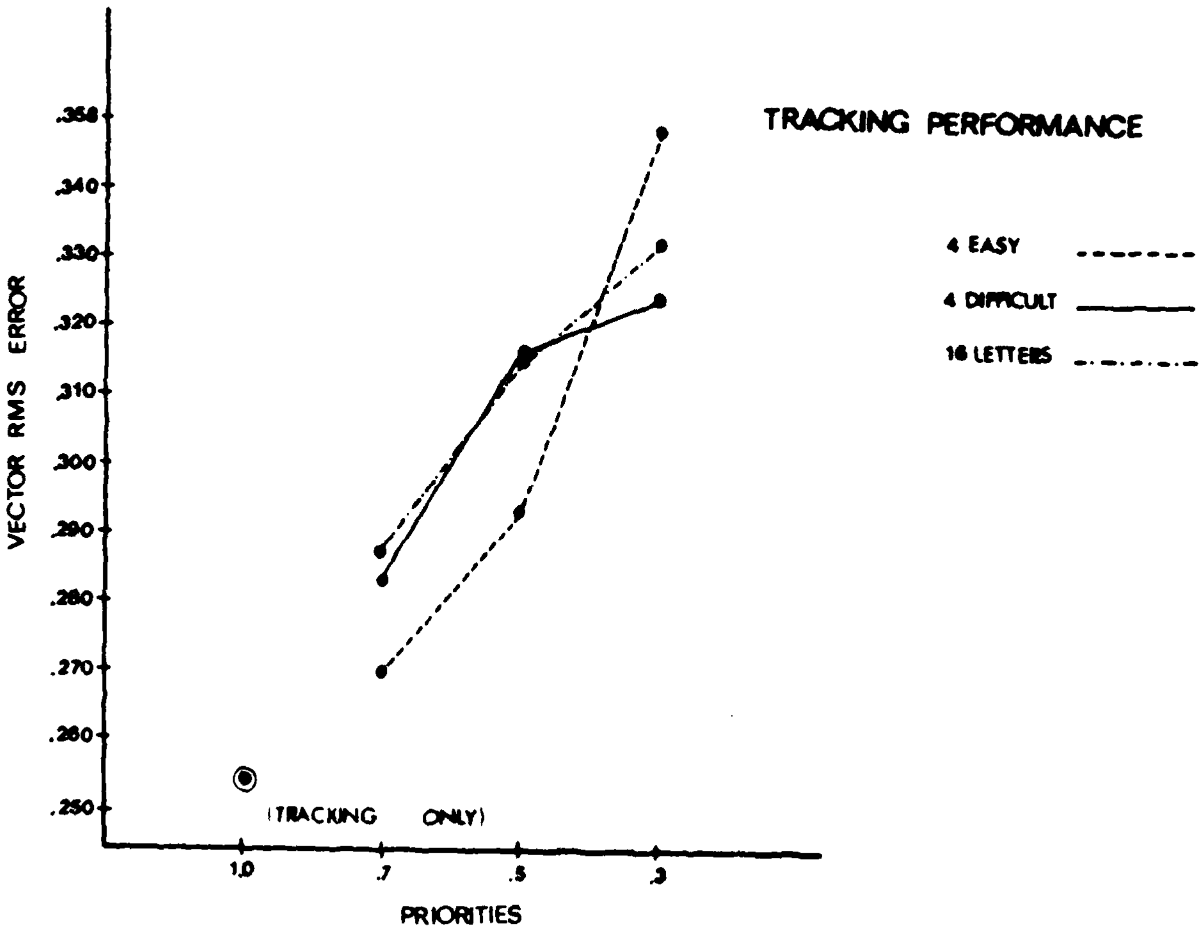

Fig. 3: Tracking performance under time-sharing conditions with the three variants of the letter typing task and manipulation of task priorities.

Table 1: Average reaction time scores (msec) and standard deviations on the letter typing task with manipulation of difficulty and priorities (N=6)

	Letter set exp. session		4 easy letters III	IV	16 letters III	IV	4 diff. letters III	IV	Sessions III	IV	$\bar{X}$
Priority	.3	$\bar{X}$	1078	1023	1376	1272	1454	1339	1303	1211	1257
Dual	.5	$\bar{X}$	1029	983	1337	1185	1403	1214	1257	1127	1192
Task	.7	$\bar{X}$	1061	913	1234	1144	1312	1158	1203	1072	1137
		$\bar{X}$	1057	973	1316	1200	1390	1237	1254	1137	
		$\bar{X}$	1015		1258		1313		1195		1195
Single Task (1.0)		$\bar{X}$	955	892	1197	1130	1122	1097	1041	1039	
		$\bar{X}$	923		1164		1110		1040		

Tracking performance when paired with the three variants of the letter typing task is summarized in Table 2. Recall that tracking difficulty itself was not manipulated.

Analysis of variance on tracking performance yielded significant main effects only for the manipulation of task priorities ($F(2,10) = 11.5$; $P < 0.01$). Letter set difficulty and experimental session did not reach statistical reliability. (Difficulty $F(2,10) < 1$, Sessions $F(1,5) = 2.88$). These findings are clearly depicted in Figure 3. The interaction between difficulty and priorities was again significant ($F(4,20) = 2.93$; $P < .05$). A separate analysis was conducted to compare the effects of the two types of typing difficulty manipulations.

Table 2: Vector RMS tracking error (percent of scale) with manipulation of task priority and letter set difficulty (N=6)

	Letter set session		4 easy letters III	4 easy letters IV	16 letters III	16 letters IV	4 diff. letters III	4 diff. letters IV	Sessions III	Sessions IV	$\bar{X}$
Priority	.3	$\bar{X}$	.369	.327	.347	.317	.335	.313	.350	.319	.334
	.5	$\bar{X}$	.285	.302	.334	.296	.335	.297	.318	.298	.308
	.7	$\bar{X}$	.269	.270	.296	.278	.290	.276	.285	.275	.280
		$\bar{X}$	.308	.300	.325	.297	.320	.295	.318	.297	.289
		$\bar{X}$	.304		.311		.307		.307		

Results for the comparison of tracking performance with 4 easy and 4 difficult sets were again conclusive. Difficulty and priority significantly interact ($F(2,10) = 5.50$; $P < .025$). Only a weak trend of interaction between difficulty and priorities was revealed in tracking performance when analysis was restricted to the 4-easy and the 16 letter set. This trend did not reach the conventional level of significance ($F(2,10) = 3.26$; $P < .10$). The trend is probably the result of the initial interaction between priorities and difficulty observed when the 16 letters task was first introduced in the third session. The interaction almost disappeared in the fourth meeting as evidenced from the three way interaction between letter difficulty, priorities and sessions ($F(2,10) = 5.75$; $P < .025$, see also table 2)

DISCUSSION

The experimental results of time sharing between tracking and the three variants of the letter typing task revealed significant effects of task difficulty, task priority and their interaction. The general pattern

Table 2: Vector RMS tracking error (percent of scale) with manipulation of task priority and letter set difficulty (N=6)

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	.5	$\bar{X}$	.285	.302	.334	.296	.335	.297	.318	.298	.308
	.7	$\bar{X}$	.269	.270	.296	.278	.290	.276	.285	.275	.280
		$\bar{X}$	.308	.300	.325	.297	.320	.295	.318	.297	.289
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DISCUSSION

The experimental results of time sharing between tracking and the three variants of the letter typing task revealed significant effects of task difficulty, task priority and their interaction. The general pattern

of dual-task interference between the two tasks corresponds to a pattern predicted by the multiple resource model for a pair of tasks that only partially overlap in their demand for processing resources. Competition for allocation of a common resource is suggested by the performance decrements observed on both tasks in the transition from single to dual task conditions. A second and more powerful indication for such competition is the significant monotonic relationship between task priority and the level of concurrent performance on both tasks. The fact that the overlap is only partial is suggested by the differential effects of the two manipulations of letter typing difficulty. These effects may also give some clues to the nature of the overlap between the tasks and the structure of their demand composition. In the following sections these arguments are examined in detail.

Tables 1 and 2 and the two figures show significant increments of tracking error and typing latency from single to dual task conditions and ordered effects of task priority. Such increments were evident even in the easiest dual-task condition, when tracking was paired with the easy version of the letter typing task. When difficulty of the letter task was increased by incrementing response difficulty or set size, typing performance further deteriorated. The strong and systematic effects of the priority manipulation which demonstrate the ability of subjects to supervise their task investments favors a resource allocation interpretation for the dual-task decrements on the two tasks, over an all-or-none interference due to structural conflicts or concurrence costs (see Navon & Gopher, 1979; Gopher & Navon, in press, for further discussion of this point). It is important to note in this context that without the manipulation of task emphasis these two sources of dual-task interference, namely scarcity of resources versus conflicts between input, output or similar factors, could

not be distinguished. Our first conclusion from the analysis of time-sharing performance of the two tasks is that tracking and the letter typing task do compete in their demands for a common limited resource. Next to be evaluated are the extent of overlap and locus of the competition. To answer these questions the effects of the two difficulty manipulations should be examined.

To recapitulate, the easy condition of letter typing includes a set 4 letters entered by two successive strokes of identical chords. Cognitive load on this task was increased by enlarging the letter set to 16 letters. Motor response demands were incremented by selecting a set of 4 letters on which letter entry codes were composed of two different chords, employing different combinations of the three middle fingers. It was assumed that the two manipulations would tap different processes or stages of task performance (Kerr, 1973).

Both increased cognitive load and response difficulty produced large increments in typing response time relative to the easy typing condition. Performance decrements were large when typing was performed singly or in dual-task conditions. In single task performance typing latency was more affected by the increase of letter set size than by the manipulation of response difficulty. In dual task conditions the effects were reversed. Increased motor difficulty produced larger decrement and interacted with task priority on both letter typing and tracking tasks. Increased cognitive load, when compared with performance on the easy typing task, led to a change in the intercept, but not the slope of the tradeoff function between ,ping and tracking due to the manipulation of task emphasis (Figure 1). It therefore appears that while manipulation of motor difficulty tapped a resource that was commonly shared by tracking and typing, increasing the better set size imposed demands on a resource that was

relevant to the typing task but not to the concurrently performed tracking task.

The differential effects of cognitive load and motor difficulty provide important support to the multiple resources viewpoint over the single capacity approach. Within a single capacity model when all tasks are assumed to compete for allocation of a common undifferentiated pool (Kahneman, 1973), the two difficulty manipulations that were shown to affect single task performance would also be expected to produce similar effects in concurrent performance. The results of the present experiment are in contrast with this prediction and support separation of resources.

Recall that the selection of the two difficulty manipulations was not arbitrary but guided by the results of an earlier study which suggested that the resource requirements of tracking tasks can be generally divided into computational resources and motor related resources, and that it is on the second component that tracking is primarily loaded (Gopher & Navon, in press). The results of the present experiment support these initial suggestions which can now be more safely utilized for the design of manual control tasks in real systems. Information on the demand structure of tracking tasks may enable us to develop guidelines to select between alternative design configurations in order to optimize workload, minimize time-sharing decrements and better utilize the processing capabilities of the human operator in complex tasks.

In light of the present results, it may also be valuable to pursue the study of types of processing resources by pairing the letter typing task with a task that is primarily loaded on the cognitive side. If the interpretation of the results is correct, then the impact of the two difficulty manipulations on dual-task performance should be reversed.

To gain a better understanding of the type of motor resource involved, it may be instructive to examine more closely the nature of motor requirements imposed by the two tasks. Tracking as configurated in the present study primarily controlled acceleration, that is, constant stick deflections by the subject led to constant acceleration changes in the movement of the controlled element on the display. Acceleration controlers are very hard to operate because control movements should be proportional not to the distance between the target and control symbols on the screen (positional errors), nor to the difference between their speed (velocity errors), but to the changes in their respective accelerations. To properly control such systems, the human is required to produce complex movement sequences and introduce leads and lags to his responses, otherwise performance may widely oscillate or fail completely (for more detailed discussions see Wickens & Gopher, 1977; Pew, 1974). When errors are detected major efforts should be devoted to the generation of appropriate control movements. It is probably not the execution of the movement itself that imposes heavy demand on the resources of the subject, but rather its planning and monitoring.

On the letter typing task the major difference between the sets of 4 easy and 4 difficult letter codes appears to be along a similar dimension. Both sets of letters require two successive strokes of three key chords. However, while those chords are repetitive in the easy letter set, finger combinations change and chord sequences are asymmetric and confusing in the set of four difficult letters. Again, the main burden appears to be the need to exercise supervisory control and to plan the generation and sequencing of motor responses. It is not response selection or response execution but rather response supervision and control that typify the load imposed by this manipulation as by the tracking task. It is for allocation

of this resource that the tracking and letter typing tasks seem to compete under time-sharing conditions.

Note that the patterns of interaction between difficulty and priorities on the two tasks appear to be different; Difficult typing is associated with larger slope for typing latency, but with smaller slope for tracking error scores. These seemingly opposing patterns are exactly what is expected if latency is construed as a linear function of the reciprocal of rate of processing. Roughly speaking, a resource unit can produce more output (accuracy or rate) when the task is easy, leading to a larger slope for performance on the easy task. On the other hand, withdrawing of a unit of resources will have to be compensated by a larger processing time of the remaining units. Typically when the task is easy the resulting increment in the processing time of the remaining units will be smaller than if the task is difficult. Thus, slopes for latency measures will tend to be smaller on easy tasks. A detailed and formal derivation of this prediction is beyond the scope of this paper and appears in Navon & Gopher (in press).

A final word should be said on the effects of practice. Although adaptive procedures were employed to adjust the initial levels of tasks for each subject, practice effects were still evident on both tasks and were more pronounced in letter typing performance. Nevertheless, practice effects did not change the general pattern of results and did not interact with other variables, except for a single interaction between session priority and difficulty which appeared in tracking performance when this task was first paired with the 16 letters typing condition. The interaction disappeared in the second session. Initial interaction between task difficulty and time-sharing requirement has been reported by other authors (Logan 1979) and attributed to initial demands on coordinating

mechanism that disappears with practice. In our study the effect of such initial effects was probably minimized due to the adaptive procedures.

Appendix A

Sets of letters for the letter typing task

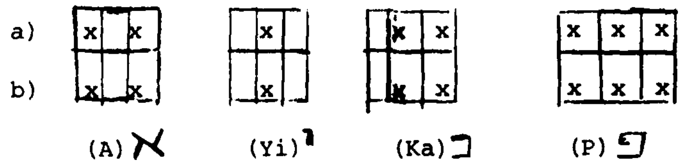
Each letter code is composed of two chords entered successively in two strokes on the letter-shape keyboard. Chords are combinations of three keys.

The three keys and the two successive strokes create together an imaginary six cell matrix. The cells of this matrix are used as graphic elements to create the codes of all letters.

Listed below are the three letter sets used in this experiment. Underneath each code is the Hebrew letter it represents. English phonetic equivalents appear in parentheses.

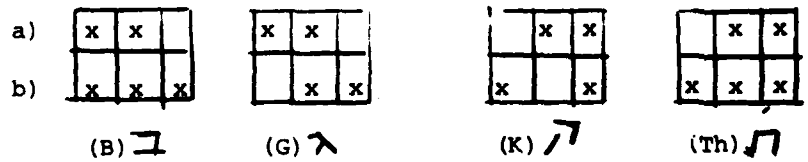
4 easy letters

Strokes



4 difficult letters

Strokes



<u>16 letters</u>: This set included the letters of the two former sets and in addition the eight following letters:

<u>Strokes</u>

a)	x	x	x
b)		x	

(D) ד

a)	x	x	x
b)		x	x

(H) ה

a)		x	x
b)		x	

(Z) ז

a)	x	x	x
b)	x		x

(CH) ח

a)	x		x
b)		x	

(T) ט

a)		x	
b)	x		x

(M) מ

a)			x
b)		x	x

(N) נ

a)	x	x	
b)	x	x	

(S) ס

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20. Abstract

A two-dimensional pursuit tracking task was paired with three variants of a letter typing task to test predictions about the effects of task difficulty and task emphasis derived from a model of multiple resources, which states that tasks can overlap to various degrees in their demand for

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resources. Under dual-task conditions, when difficulty and priorities of tasks are jointly manipulated, difficulty parameters that tap a processing resources shared by both tasks interact with priorities, while parameters that are relevant to one task only have additive effects on performance. In the present experiment a fixed difficulty tracking task was paired with a letter typing task on which difficulty was manipulated by varying cognitive or motor factors. In addition, task priorities were manipulated and the instantaneous difference between actual and desired performance was continuously displayed to the subjects. Task priority in dual-task conditions had large effect on the performance of the two tasks suggesting the existence of competition for resources. Both types of difficulty manipulations had large effects on performance. However, only motor difficulty interacted with priorities. The results are interpreted to indicate that joint performance of typing and tracking mainly compete for motor-related resources, while the size of the stimulus set tap a separate resource which is primarily relevant to the letter typing task.

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